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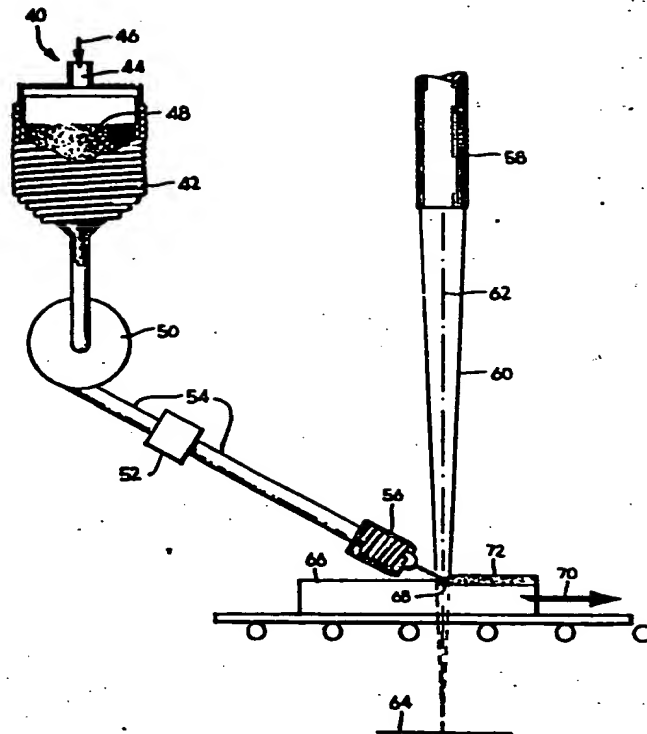
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(54) **Method and apparatus for repairing metal in an article.**

(57) In the repair of a metallic article portion, a metal powder and laser beam are applied concurrently, the laser beam being applied in a power density range of  $10^4$  to  $10^6$  watts per square centimeter at an interaction time between the laser and the article and powder of 0.005-2 seconds to generate a repair layer. Apparatus for delivering a consistent, continuous flow of powder comprises the combination of an enclosed powder reservoir (40) including means (44) to introduce a gas under pressure, a mechanical means (50) to feed powder into a conduit (54), a conduit vibrating means (52), and a fluid-cooled powder delivery nozzle (56).

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**Fig 5**

~~PATENT~~

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METHOD AND APPARATUS FOR  
REPAIRING METAL IN AN ARTICLE

This invention relates to the repair of a metallic portion of an article and, more particularly, to such a repair using a metal powder and a laser beam.

~~BACKGROUND OF THE INVENTION~~

5           Modern gas turbine engines, particularly of the type designed primarily for aircraft applications, include components which are expensive to manufacture because of their complex design and materials of construction. During normal operation of such apparatus, some components  
10 can experience events such as normal wear or thermal damage. In addition, mishaps such as machining errors or other inadvertent damage can occur during initial manufacture. For example, such events or damage can occur in connection with compressor or turbine spools or disks.

15           It has been found that, in respect to localized repair of a portion of an article rather than replacement of the portion, ordinary known means of repair such as electron beam welding and gas tungsten arc welding can adversely affect properties of the material of  
20 construction because of relatively high heat input which

0176942

results in distortion and a relatively deep heat affected zone. Such an excessive heat distribution has been found to cause component cracking which is particularly critical in rotating components such as wheels, drums, and spools of gas turbine engines.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide an improved method for repairing a damaged metallic portion of an article to recreate its original configuration and material while reducing adverse effects on the article resulting from the method by limiting the extent of the heat affected zone.

Another object is to provide such a repair method which combines the use of metal repair powder of substantially the same composition as a metal portion of an article and a laser beam for the consolidation of a repair layer or plurality of superimposed repair layers on the article.

Still another object is to provide apparatus of components which in combination provide a consistent continuous powder flow to enable practice of the repair method.

These and other objects and advantages will be more fully understood from the following detailed drawing, description, and examples, all of which are intended to be representative of, rather than in any way limiting on, the scope of the present invention.

Briefly, one form of the method of the present invention for repairing an article having an article portion of a metallic material includes the steps of concurrently applying to the article portion a metal powder, alone or in combination with another powder such as an abrasive, and a laser beam. The metal powder is of

a composition substantially the same as that of the metallic material of the article portion and preferably is applied at a rate in the range about 2-15 grams per minute. The laser is applied, in a laser beam spot, to the powder and the article portion beneath the powder within a power density range of  $10^4$  to  $10^6$  watts per square centimeter to generate a molten interaction zone from the metal powder and the metallic material of the article portion. In order to further control the resultant heat affected zone, an interaction time is maintained in the range of 0.005-2 seconds between the laser beam spot and the powder along with the article portion beneath the powder, for example by relative lateral movement, to enable progressive movement, cooling, and solidification of the molten interaction zone. This controls and reduces the extent of the heat affected zone in the article portion and provides a repair layer on the article portion consolidated from the applied powder and metallic material of the portion. Other forms of the invention contemplate repeating such steps, if desired, to provide a plurality of superimposed, bonded-together repair layers using the preceding repair layer as the "article portion" for the concurrent application of metal powder and laser beam.

One form of the apparatus of the present invention comprises a unique combination of components including an enclosed, preferably heated powder reservoir, means to introduce inert gas under pressure into the reservoir, a mechanical volumetric powder feed means, a powder vibrator, and a fluid-cooled delivery nozzle. Together, such components deliver a consistent, continuous flow of powder.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a fragmentary, partially sectional, diagrammatic view of a portion of a compressor spool with which the present invention can be used.

5           FIGURE 2 is an enlarged fragmentary portion of spool 10 of Figure 1.

FIGURES 3 and 4 are forms of specimens used in the evaluation of the present invention.

10           FIGURE 5 is a diagrammatic, partially sectional view of the apparatus practicing the method of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the initial manufacture as well as in the operation of aircraft gas turbine engine components, damage from manufacturing error as well as from operational thermal cycling, wear, part interference, etc. can occur. Because of the relative high cost of such components, there are many potential benefits which can be obtained by their repair rather than their replacement. Although such damage can occur to stationary as well as rotating parts, damage is particularly critical in the rotating components because of the stresses generated in operation, during rotation. Because damaged portions of components can be relatively thin, known methods of repair, for example to build up undersized portions, can produce heat affected zones inordinately large and detrimental to the operation capability of the component.

25           An example of one gas turbine engine component with which the present invention has been used is a compressor rotor including a plurality of disk-type members disposed radially inwardly from a drum or spool

0176942

surface. One such compressor rotor is shown in U.S. Patent 3,765,795, ~~issued October 16, 1973, and assigned to the assignee of the present invention.~~ A portion of such a spool is shown in the fragmentary, partially sectional, diagrammatic view of Figure 1 including a four-stage  
5 segment of a larger compressor rotor joined such as through bolting to an adjacent member.

With reference to Figure 1, such a spool or drum member is shown generally at 10 as comprising four disk  
10 portions having a central opening and disposed for rotation about engine axis 12. Drum or spool 10 is joined to adjacent rotating member 14 through bolt means 16 which also connects member 14 to an adjacent spool 18. Rotating drum 10 and member 14 carry rotating blading members 20  
15 which cooperate with stator vanes 22, as is well known in the axial flow compressor art.

In respect to the present invention, a lip portion 24 of spool 10, enlarged in Figure 2, cooperates with an adjacent portion of member 14 during operation.  
20 Portion 24 can be subject to operation damage such as through wear, erosion, thermal fatigue, etc. Enlarged Figure 2 showing an end portion of spool 10 which includes lip 24 shows, in phantom, material 23 worn from lip 24. Because it is desired in such a component to maintain a  
25 smooth airflow therethrough and minimize leakage, excessive clearances generated by such damage can affect performance of the component. As can be appreciated from the complexity of the structure involved, it is far more attractive to repair rather than to replace such a  
30 member. However, because of the relatively thin sectional area involved, ordinary repair methods have been found to be undesirable and detrimental to the metal from which the member has been constructed.

During the evaluation of the present invention, a  
35 variety of specimens were prepared including those of the

0176942

types shown in Figures 3 and 4. Such specimens were intended to evaluate the effect of a laser beam in melting powder to be consolidated with a substrate or a metallic material of an article portion. The object of such  
5 consolidation and rebuilding, sometimes called "Reverse Machining" method, is to provide a repair layer or layers of the same material as that from which the article was made, while minimizing the heat affected zone as an undesirable result of any such method. In general, the  
10 heat affected zone is that portion of the material of an article which has experienced relatively high localized heat, for example as in brazing, welding, and other types of processes, including repair processes, in which heat energy is applied to a material surface. As the result of  
15 such application of heat, the mechanical properties of the material can be significantly reduced, sometimes to the point at which the article is no longer suitable for its intended purpose without some subsequent restrengthening procedure. Because of the complexity of an article such  
20 as the compressor rotor portion shown in Figure 1, it is not economically attractive to restrengthen the member after a repair process which generates an inordinately large heat affected zone, particularly in such a highly stressed member.

25 During the evaluation of the present invention, coupons shown in the perspective, partially sectional views of Figures 3 and 4 were used. Test repair layers 25 and 27 in Figure 3, of approximately 1.5 inches in length, were deposited along the top surface 29 of the specimen.  
30 In one series of tests, metal powder and the laser beam spot were applied concurrently in two passes made along the test surface: the first in which the central axis of the laser beam spot was at the edge 26 of the specimen in Figure 3; and the second in which the axis was along a  
35 line identified as broken line 28 and 0.065 inches from edge 26.



In these evaluations, the powder feed rate was in the range of about 5-10 grams per minute, within the broad range of 1-30 grams per minute according to the present invention, concurrently with the application of the laser beam from a 5000 watt continuous wave CO<sub>2</sub> laser manufactured by Spectra Physics as Model 975 and maintained at a power setting of 1.8-2.0 kilowatts which corresponds to power densities in the range of  $3.5-3.9 \times 10^4$  watts per square centimeter. The beam spot size was in the range of 0.05-0.15 inches. In these examples, a molten interaction zone was created from the metal powder and the metallic material of the coupon described above. The coupons were made from a nickel base alloy commercially available as IN718 alloy and the powder was IN718 alloy having a composition substantially the same as that of the coupon material.

In all tests in which the first pass laser beam axis was at edge 26, an internal or interdendritic crack occurred in the repair layer. However, in other tests using the same materials and apparatus and in which the location of the axis of the laser beam spot in the first pass was moved about 0.01-0.02" (nominally 0.15") away from edge 26, no such cracks were observed. Therefore, the method of the present invention recognizes that in the method of repairing an article portion including an edge of the article, it is critical to direct the central axis of a laser beam spot away from the edge of the article in order to avoid cracking of the repair layer deposits. In the evaluation in which the first pass beam spot axis was away from the edge of the article, three vertical layers, each including two side-by-side passes as described above and displaced 0.06 inches, did not result in cracking of the deposit. Therefore, a plurality of repair layers can be superimposed one upon the other according to the method of the present invention without generating cracks in the

0176942

deposit upon cooling. As used herein, the designation "edge of an article" means the intersection of surfaces or planes which, when examined in planar cross section, results in an abrupt change in angle. For example, an edge of the article can be a relatively sharp outside corner of a radius of about 0.1 inch or less.

In another series of evaluations, the arrangement shown in Figure 4 was used. Although the materials and conditions were the same, additional IN718 alloy powder 30 was preplaced in a groove along the side of the coupon. Such groove was defined by the coupon and sheet 32 held with the coupon body 33 as shown in Figure 4. This was intended to create a more favorable heat transfer condition with the extra powder absorbing photon energy and providing additional protection to the edge from excessive melting. The additional powder 30 can assist in reducing peak temperature by absorbing energy required for melting (heat of fusion).

A further evaluation of the present invention involved a portion of the repair of a gas turbine engine fan blade airfoil interlock surface which had been damaged during manufacture. The blade was made of a titanium alloy commercially available as Ti-6-4 alloy. The powder, employed in the above-described method and apparatus to repair the blade, was -35 mesh titanium powder conforming to Aerospace Material Specification (AMS) 4928H, ELI grade. In this example, the metal powder feed rate, assisted by pressurized argon gas, was 4.5-5.5 grams per minute, with the powder feed nozzle to workpiece at an angle of about 45-50°. The above-described 5000 watt laser was used in the power range of 3.5-4 kilowatts which corresponds to power densities in the range of  $6.9-7.9 \times 10^4$  watts per square centimeter. The beam spot size was about 0.100 inch at an interaction time of about 0.27 seconds. In this example, multiple layers were

0176942

superimposed on the workpiece surface, as described above, each layer with a powder thickness of about 0.018-0.020 inch with a total weld buildup not exceeding 0.140 inch.

As a result of these tests and evaluations, the power density for practice of the method of the present invention was defined as being in the range of  $10^4$  to  $10^6$  watts per square centimeter. Below the lower limit, energy is reflected and the beam will not be sufficiently absorbed by the substrate metallic material of the article, leading to lack of fusion or consolidation between the powder and the article substrate material. It is below the threshold required for effective coupling of the beam to the material. In addition, power densities higher than  $10^6$  watts per square centimeter can produce excessive vaporization at the article surface and provide a deeper molten zone. From such higher power densities, a wider heat affected zone is created with resultant higher residual stresses between the metallic material of the article portion and the added resolidification cast structure of the repair layer after cooling of the molten zone.

The method of the present invention recognizes the need for controlling the interaction time between the laser beam and the article material with its superimposed powder. Therefore, at the power densities defined for the present invention, it has been recognized that, in a preferred form, an interaction time of 0.1-2 seconds is necessary for such control. Interaction time is defined as the ratio of beam spot size to relative lateral movement between the laser beam spot and the article portion.

It has been recognized that the method of the present invention can be operated an an interaction time of as low as 0.005 second provided that the power density

0176942

domain is maintained within the range of  $10^4$  to  $10^6$  watts per square centimeter. The following table presents typical, calculated relationships between laser beam spot size, relative lateral movement represented by table speed, and interaction time, within the scope of the method of the present invention.

	<u>SPOT SIZE</u> <u>(inches)</u>	<u>TABLE SPEED</u> <u>(inches per sec.)</u>	<u>INTERACTION TIME</u> <u>(seconds)</u>
10	0.005	0.5	0.01
	0.200	0.5	0.4
	0.005	0.1	0.05
	0.200	0.1	2.0
15	0.005	1.0	0.005
	0.200	1.0	0.2

Therefore, the method of the present invention minimizes the extent of the heat affected zone resulting from the application of the laser beam to the combination of a powder superimposed on the metallic material of an article portion by defining the limits of the power density and the interaction time: the power density is in the range of  $10^4$  to  $10^6$  watts per square centimeter in combination with the interaction time in the range of 0.005-2 seconds between the beam spot and the powder and article portion beneath the powder.

The apparatus of the present invention and that used in the evaluation of the method is shown in the diagrammatic sectional view of Figure 5. The apparatus includes an enclosed powder reservoir shown generally at 40, heated by heating coils 42 for the purpose of controlling the moisture content at a low level in the powder. Also included is a gas inlet port 44 through which a preferably dry inert gas such as argon, represented by arrow 46, is introduced to maintain powder

48 in reservoir 40 under pressure and to assist in powder transport. Associated with the powder reservoir is a mechanical, volumetric powder feed mechanism such as powder feed wheel 50 of a type commercially available.

5 For example, the type used in one form of the apparatus of the present invention was a modified Metco powder feed "L" type wheel.

Downstream of wheel 50 is a vibrator such as air actuated vibrator 52 associated with conduit 54 to inhibit powder particles moving in conduit 54 from adhering one to the other or to walls of the conduit 54. Conduit 54 terminates in a water-cooled powder delivery nozzle 56 which directs the powder, assisted by the pressurized inert gas, in a consistent flow, such as toward an article or workpiece surface. It has been found that reflection from the laser beam can result in clogging of powder passing through nozzle 56. Therefore, such a nozzle, preferably having at least a tip portion made of a material, such as copper or aluminum, which is highly reflective to the wave length of the laser used, is fluid cooled, such as by water, to avoid such problem and to assist in a consistent flow of powder. Such consistent flow of powder results from the combination of use of powder maintained in a low moisture condition, under a positive inert gas pressure, being fed by a mechanical, volumetric powder feed mechanism along with a powder vibrator, and a cooled nozzle through which the powder passes toward the article surface in the laser beam spot.

Associated with the apparatus of the present invention is a laser 58 emitting a beam 60 having a beam axis 62. Beam 60 has a focal plane 64 beneath article portion or workpiece surface 66 to provide at the surface a beam spot 68 of a size in the range of 0.005-0.2 inches, and preferably in the range of 0.05-0.15 inches. As was described above, the laser beam was applied in the power

0176942

density range of  $10^4$  to  $10^6$  watts per square  
centimeter while controlling the interaction time between  
the beam spot and the powder and article portion beneath  
the powder in the range of 0.005-2 seconds. Such control  
5 is obtained by relative lateral motion shown by arrow 70,  
for example from a table moving the article in the  
direction shown at a rate to provide the desired  
interaction time.

The powder is fed from nozzle 56 at an angle in  
10 the range of about 35-60 degrees from the article surface  
and preferably in the range of about 40-55 degrees.  
Greater than about 60 degrees makes it difficult for the  
nozzle and powder to avoid premature interaction with the  
laser beam, and less than about 35 degrees makes it  
15 difficult to deliver the powder concurrently with the  
laser beam at the spot desired on the article surface. As  
the powder and laser beam are applied concurrently to the  
article surface, a molten interaction zone is generated in  
the area of the beam spot. As relative lateral movement  
20 is provided between the laser beam spot and the article  
carrying its superimposed powder, progressive movement,  
cooling and solidification of the molten interaction zone  
occurs. This provides consolidated repair layer 72 as  
shown in Figure 5. Such a consolidated layer resulting  
25 from the practice of the present invention also is shown  
in phantom at 23 in Figure 2.

After application and consolidation, excess of  
the repair layer material added can be shaped to a desired  
configuration, such as by machining, grinding, dressing of  
30 abrasive particles, etc. In this way, there is provided a  
repaired article having a minimized heat affected zone and  
desired mechanical properties.

Although the present invention has been described  
in connection with specific examples and embodiments, it  
35 will be understood by those skilled in the arts involved,

0176942

for example metallurgy, metal joining, and laser technology, that the present invention is capable of modification without departing from its scope as represented by the appended claims.

0176942

CLAIMS

~~What is claimed is:~~

1. In a method for repairing an article having an article portion of a metallic material, the steps of:  
concurrently applying to the article portion a laser beam and a powder comprising metal powder;  
5 the metal powder being of a composition substantially the same as the metallic material of the article portion;  
the laser being applied, at a laser beam spot, to the powder and the article portion beneath the powder in a power density range of  $10^4$  to  $10^6$  watts  
10 per square centimeter to generate a molten interaction zone from the metal powder and the metallic material of the article portion, while  
maintaining an interaction time in the range  
15 of 0.005-2 seconds between the beam and the powder and article portion beneath the powder thereby reducing the heat affected zone in the article portion and providing a repair layer on the article portion consolidated from the powder and metallic material of the portion.
2. The method of claim 1 in which relative lateral movement is provided between the laser beam spot and the article portion to cooperate with the power density in maintaining the interaction time and to enable  
5 progressive movement, cooling and resolidification of the molten interaction zone.
3. The method of claim 1 in which the laser beam is of a continuous wave type.



4. The method of claim 1 wherein:  
the powder is applied at a rate in the range  
of about 1-30 grams per minute; and  
the laser is applied with a beam spot size  
5 at the article portion in the range of about 0.005-0.2  
inches.

5. The method of claim 1 for repairing an  
article having an article portion of a metallic material,  
the portion including an edge of the article, wherein the  
laser is applied with the central axis of the beam spot  
10 being away from the edge of the article.

6. The method of claim 1 in which the powder is  
provided in a substantially moisture-free condition.

7. The method of claim 6 in which the powder is  
heated to remove moisture prior to applying the powder to  
the article portion.

8. The method of claim 1 wherein the sequence  
of steps is repeated to provide a plurality of  
superimposed, bonded-together repair layers using the  
preceding repair layer as the article portion for the  
5 concurrent application of powder and laser beam.

9. Apparatus for delivering a consistent,  
continuous flow of powder comprising, in combination:  
an enclosed powder reservoir;  
means to introduce a gas under pressure into  
5 the reservoir;

a mechanical, volumetric powder feed means  
to move powder from the reservoir into a powder conduit;

a conduit vibrating means to vibrate the  
powder conduit and the powder therein; and

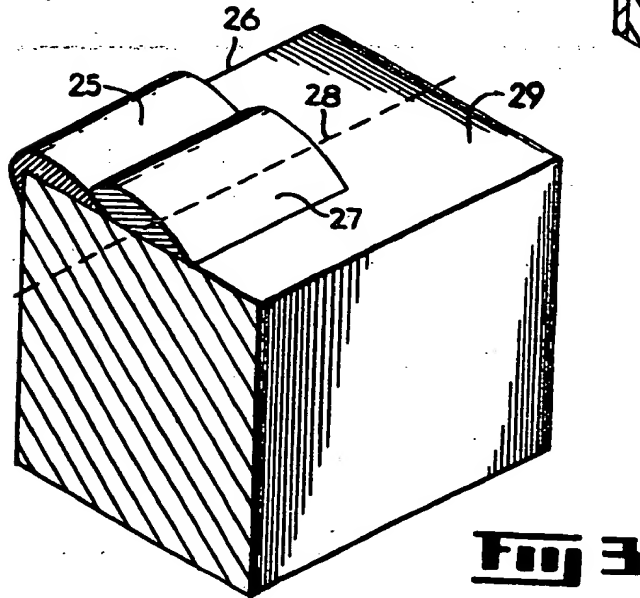
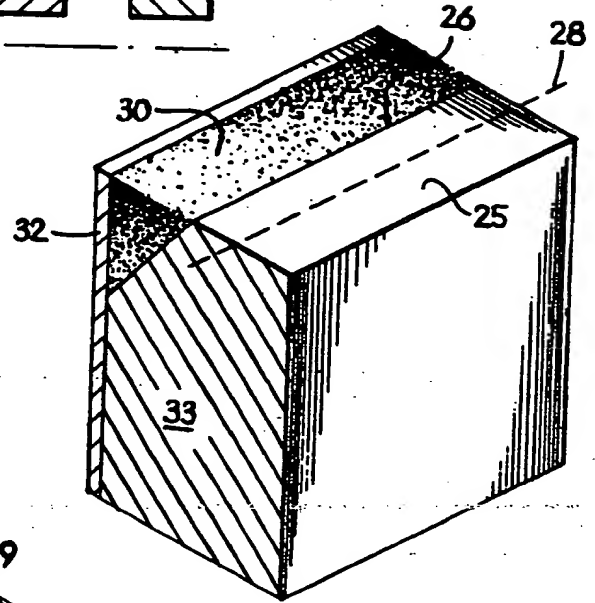
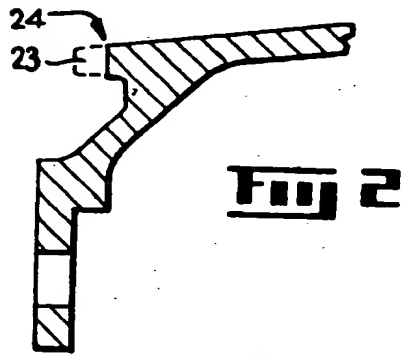
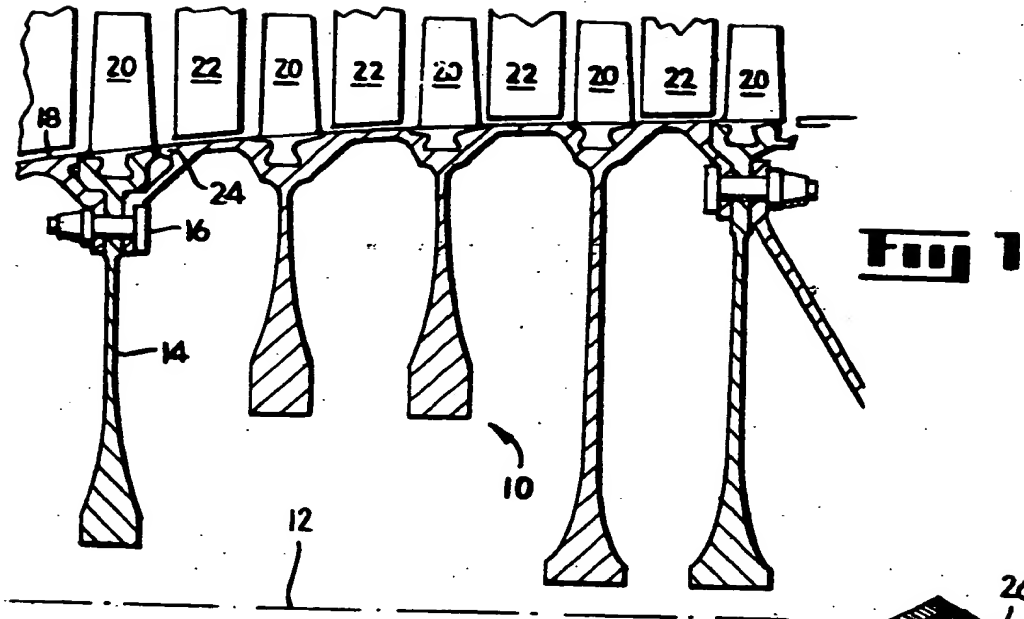
10 a fluid-cooled powder delivery nozzle  
connected with the powder conduit to receive powder from  
the conduit for delivery from the nozzle.

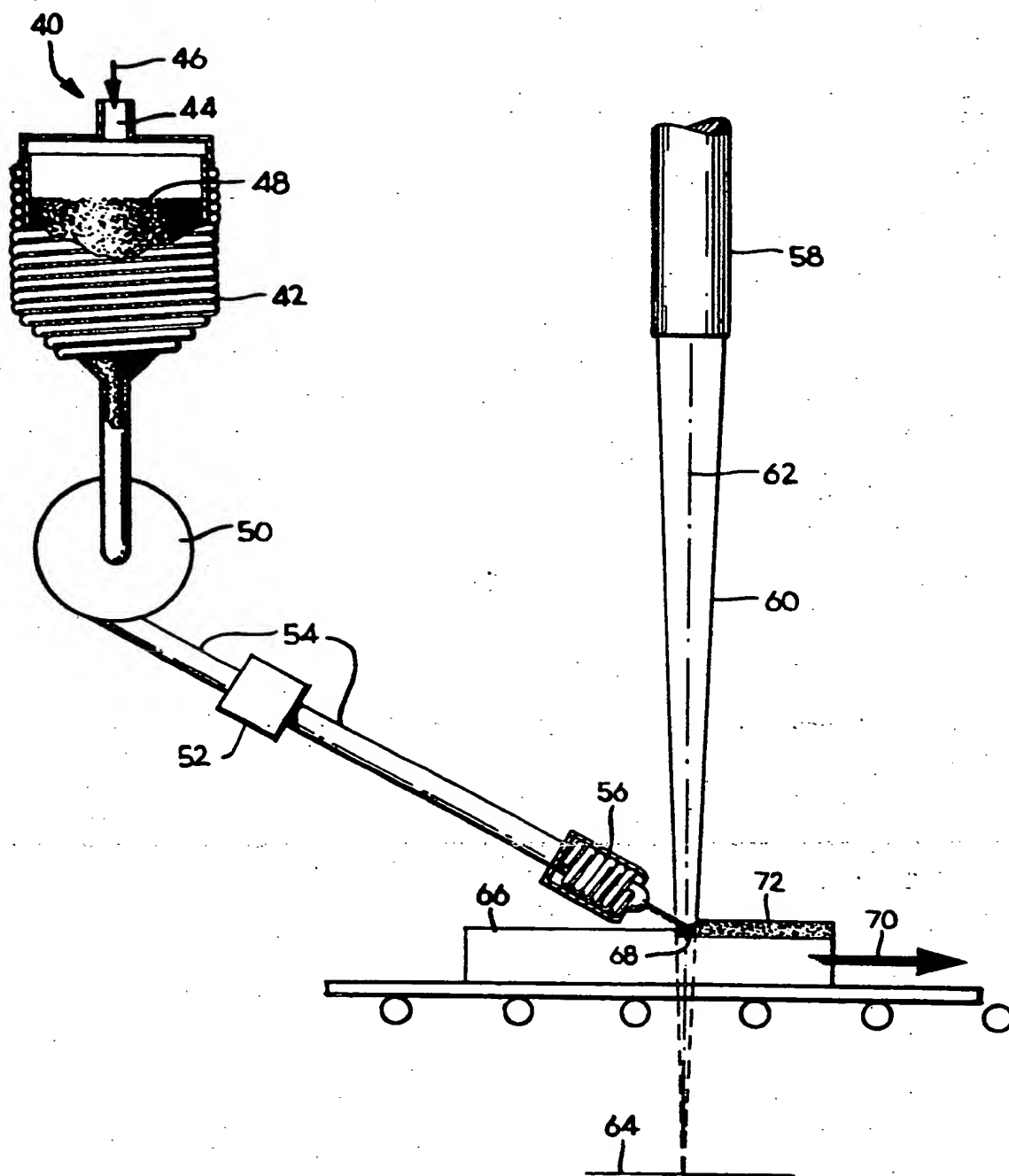
0176942

10. The apparatus of claim 9 in which the reservoir is heated to maintain low moisture in powder within the reservoir.

11. The apparatus of claim 9 in which the powder delivery nozzle includes at least a tip portion made of a material which is highly reflective to the wave length of a laser used in combination with the apparatus.

LHS:rjc  
09/20/84



**Fig 5**



DOCUMENTS CONSIDERED TO BE RELEVANT				EP 85112132.7
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)	
A	US - A - 4 323 756 (BROWN et al.) * Totality * --	1-4,8	B 23 P 6/00 B 23 K 26/00	
A	US - A - 4 243 867 (EARLE AND LENZEN) * Fig. 1 *	1		
A	US - A - 4 048 459 (EARLE) * Fig. 3 * -----			
			TECHNICAL FIELDS SEARCHED (Int. Cl. 4)	
			B 23 K 26/00 B 23 P 6/00	
The present search report has been drawn up for all claims				
Place of search VIENNA		Date of completion of the search 19-12-1985	Examiner TROJAN	
CATEGORY OF CITED DOCUMENTS				
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document				